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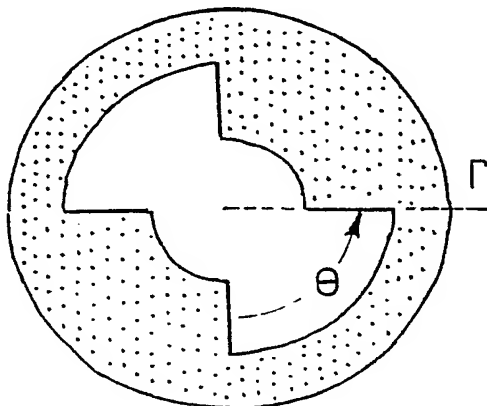
(57) Abstract

The present invention relates to a laser system and device for remodelling the anterior surface of the cornea. These are constructed from a laser source suitable for photoablation and preferably having uniform flux density distribution such as can be generated and controlled by a laser beam homogenizer (3) and monitor (5) respectively, and a laser beam characterizing system consisting of a mask rotator and a mask translator and a series of associated non-erodible masks (7), one of which is fitted at a time per correction in the mask rotator or translator, and wherein this mask has one or more windows with a well defined form corresponding with a determined symmetrical profile change on the cornea. This remodelling has for its objective to correct the optical disorders of the eye. This invention provides a new method and device for performing the remodelling more accurately and more stably in time. Characteristic here is that the above mentioned masks with window(s) have a central portion, the shape of which corresponds in mathematical manner with the topographical change of the optical zone of the cornea, and a peripheral portion, the shape of which corresponds in mathematical manner with the topographical change of a surrounding stabilization zone in accordance with the biodynamic properties of the corneal layers. This stabilization zone, where the remodelled surface gradually transposes into the original cornea surface, is required for the stability of the curvature correction in the central optical zone.

1

DEVICE, MASK AND METHOD FOR ADAPTING THE CORNEAL SURFACE OF AN EYE

The present invention relates to a device, masks and a method for adapting the corneal surface of an eye.

Background of the invention

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Refractive surgery is a field of intense research in ophthalmology, the objective being to correct in a surgical manner frequently occurring sight disorders or ametropias such as myopia (short-sightedness), hyperopia (long-sighted-
10 ness), astigmatism and combinations of the above, in order to replace spectacles or contact lenses.

The invention relates to that branch of refractive surgery which attempts to correct the above mentioned defects by means of a suitable laser device which removes
15 tissue from the front of the corneal stroma by controlled volumetric ablation, whereby this surface is remodelled in order to improve the optical properties of the eye. This method of refractive surgery is called "photorefractive keratectomy" or "laser-refractive keratoplasty" and consists
20 of "grinding" or "remodelling" the cornea by means of laser photoablation.

Different methods and devices for ophthalmic laser surgery are described in the European patent applications EP-A-0151869, EP-A-0247260, EP-A-0207648, EP-A-0209902.
25 Other systems for surface remodelling are described in the European patent applications EP-A-0280414, EP-A-0274205, EP-A-0225913 and EP-A-0261193.

These known techniques are based on ultraviolet radiation preferably having a wavelength of 193 nanometers
30 such as is provided for example by a pulsed excimer laser operating on argon fluoride.

At 193 nanometers the photons have sufficient energy (6.4 eV) to break covalent bondings in molecules.

The effect can best be compared macroscopically with an "evaporation" of the molecules, called photoablation, which takes place almost without damage to the surrounding tissues (figure 5). Only molecules directly exposed to the 5 radiation are ablated. The effect amounts to an exact and controllable removal of tissue. With a pulsed excimer laser on ArF for instance, between 0.1 and 1 micrometer (mμ) can be ablated per shot or laser pulse.

A photorefractive operation may proceed as follows: 10 the refraction of the cornea and lens, which together focus the light on the retina, is examined; the curvature of the cornea in the different meridians is determined with a keratometer; the required curvature of the cornea is computated in the different meridians so that the light focuses on the 15 retina; the local thickness of the layer of tissue for removal in order to obtain this required curvature is computated. As fig. 1 shows, short-sightedness is corrected by flattening the cornea curvature and long-sightedness (fig. 2) by enlarging the cornea curvature. Astigmatism 20 requires the reduction or increase of the radius of curvature in one meridian (fig. 3 and 4). The outer epithelial layer of approximately 50 micrometer thickness is carefully removed for instance with a No. 57 "hockeystick" Beaver knife.

25   The laser needs approximately 30 seconds to grind the cornea and the whole procedure can be carried out under local anesthesia, and optionally as out-patient treatment.

In clinical practice this technique is only acceptable if the cornea remains transparent and the induced 30 refractive correction is predictable and stable.

A first art consists of dosing laser flux such that the desired quantity of tissue is removed to change the curvature as indicated in the figures 1, 2, 3 and 4.

Suggested in the European patent application EP-A- 35 0151869 is the performing of a controlled photoablation of the cornea using a scanning movement over the cornea with a beam of an excimer laser.

In European patent application EP-A-0257836 the cornea curvature correction is achieved by exposing the cornea to a sequence of mask openings of differing, though related, surface area, optionally assembled on a rotating

5 disc, wherein the cumulative effect is to expose particular zones in relation to others such that the desired net cornea curvature results, either with or without a transition ring around the operative zone to stimulate re-growth of the epithelium.

10   It is suggested in EP-A-0261193 to characterize the laser beam by an erodible mask, also called a "phantom lens" or by a mask of a material having differing transmission characteristics over the shielded zone and with a predetermined resistance profile for the laser beam.

15   Proposed in EP-A-0207648 is to achieve the remodelling effect by a controlled change in the size of the projected laser spot and to use this either through an indexable mask or mirror in the form of a plate with a collection of round or annular openings of differing

20 diameter. Proposed in EP-A-0257836 as an alternative to the central opaque spot at the annular opening is an openable, reflective umbrella.

     It is proposed in various patents to vary the size of the laser beam through an iris diaphragm, the central aper-

25 ture of which, like a photographic diaphragm, can be made larger or smaller.

     Proposed in EP-A-0224322 is the varying of the shape and size of the exposed zone by means of an optical system with a "beam-shaping opening or stop", and axially movable

30 on a converging or diverging portion of the laser beam.

     In the article by Prof. L. Missotten, "Experimental Laser Keratomileusis" (co-authors R. Boving, G. Francois and Dr. C. Coutteel M.D.; published in no. 220 of Bulletin de la Société Belge d'Ophtalmologie; p.103-120, 1987) it is propo-

35 sed to modulate a uniform bundle of ultraviolet light of an excimer according to the following principle: if it wished (fig. 6) to erode by photoablation a circular symmetrical profile D on a surface, this can be done by causing a mask C

4

with one (or more) window(s) to rotate in the beam bundle
above the surface for eroding. The mask has a rotation
centre coinciding with the centre of the desired circular
symmetrical profile. The shape of the window (or windows) is
5 such that for each distance r from the rotation centre the
aperture theta is directly proportional to the thickness of
the tissue for removal.

In wholly analogous manner (fig. 7) an elongate pro-
file F can be eroded in a surface using a mask E with one
10 (or more) window(s) which is moved forward "slidingly" in
the beam bundle in accordance with the lengthwise direction
of the profile perpendicularly to the axis of the laser
beam, and wherein the opening distance of the window along
the axis of translation (Y-axis) is proportional for each
15 distance x from the profile to the thickness of this profile
for eroding at the corresponding position.

Both principles, the rotating and the sliding mask,
can be applied in different ways in photorefractive surgery.

As is described in the above mentioned publication, a
20 spherically more negative lens can be ground on a convex
surface by means of a mask with a window whereof the
aperture is maximal in the centre and which gradually
decreases towards the edge of the optical zone, where it
reaches zero.

25 This mask could be used to give the cornea a flatter
curvature (myopia correction), but the corneal tissues
undergo a recovery process after photoablation. The
epithelium may exhibit a hyperplasia (fig. 8) and the stroma
forms new connective tissue under the epithelium. Both these
30 phenomena change the curvature and the refraction of the
anterior surface in a manner difficult to predict. The most
important optically refractive surface is namely the air
(refractive index 1)-tear film (refractive index 1.33)
transition and not the epithelium-stroma transition.

35 Analogously, a spherically more positive lens can be
ground on a convex surface by means of a mask with a window
whereof the aperture is minimal in the centre and which

gradually increases towards the edge of the optical zone,
where the aperture is maximal.

　　　　Such a mask can be used to grind on the cornea a zone
with a smaller radius of curvature. Resulting however on the
5　surface of the cornea is an abrupt denivelation on the edge
of the ground zone. The hyperplasia of the epithelium (fig.
9) and the deposition of newly formed connective tissue on
this place reduce the optical effect of the curvature
correction in a manner difficult to predict, as explained
10　above. The same problem arises if it is wished to grind a
cylindrically more positive lens on a convex surface with a
"sliding" mask. This mask is subjected to a translation and
the zone for ablation is restricted by a second mask to a
circular zone centrally on the cornea. Here also an abrupt
15　denivelation is created whereby due to the recovery process·
of the corneal layers a part of the optical correction is
abolished.

　　　　Experiments on rabbit eyes demonstrate that the prin-
ciple of a rotating or sliding mask as described in the
20　above mentioned article, is usable for remodelling a corneal
surface. The corrections obtained are not however stable in
time.

　　　　The laser normally removes no more than 50 micron,
roughly 10% of the total thickness of the cornea (the Bowman
25　layer and the surface layers of the stroma).

　　　　The eye must remain covered for several days to give
the epithelium the opportunity to grow over the naked, remo-
delled stroma surface, and to heal. The fibroblasts in the
stroma react to a keratectomy by producing collagen under
30　the epithelium. This can be greatly inhibited by local
administering of corticosteroids. (Corneal repair following
Keratectomy; S. Tuft et al, Investigative Ophthalmology and
Visual Science, Vol. 30, No. 8, August 1989). In order to
stabilize the optical correction in the post-operative
35　period local administering of steroids is a first important
step.

　　　　The overlying epithelium consists on the other hand
of very strongly interconnected cells, firmly joined to each

6

other by desmosomes. The hyperplasia of the corneal
epithelium is less easily influenced by medication. However,
the contour of the stroma has an influence on the
hyperplasia of the epithelium.

5   This can be explained by a property of the epithelium
comparable to the surface tension of liquids: the surface
layer of the epithelium has a tendency to contract so that
the total outer surface area of the epithelium remains as
small as possible.

10   Where liquid molecules are held together by cohesion
forces, the surface epithelium cells are held together by
so-called "zonulae occludentes" or "tight-junctions". We
could call this property the "slow surface tension" of the
epithelium, because the effect thereof only becomes manifest

15 after some time. The typical change of shape that an
epithelial cell undergoes during its migration from the
basal cell layer to the surface layer can also partly be
explained by the fact that the surface cells exert a force
on each other via their zonulae occludentes (drawing on p.84

20 of Histology of the Human Eye by Hogan MJ, Alvarado JA,
Weddell JE: published by W.B. Saunders Company, West
Washington Square, Philadelphia PA 19105).

          This so-called "slow surface tension" is a biodynamic
property of the epithelium which is both favourable and

25 unfavourable for photorefractive surgery: the epithelium
covers the irregularities and provides a smooth optically
refractive surface. The advantage is that the surface of the
cornea does not have to be ground with the precision of a
lens. The epithelium in any case grows quickly over small

30 bumps and cavities.

          Larger bumps and level differences are however also
evened out by this epithelium, such as for example the sharp
discontinuity at the edge between the ablated and not
ablated area during remodelling to a spherically more

35 positive lens (fig. 8). Such a discontinuity somewhat
delays, but does not prevent, the regrowth of the epithelium
over the operated zone. After healing even a hyperplasia of
the epithelium can be expected. This reduces the optical

effect of the curvature correction in a manner difficult to
predict. Ultimately, the most important optically refractive
surface is the air-tear film transition and not the
epithelium-stroma transition.

5   Another example is the Frensel type optical contour
on the anterior surface of the cornea as already proposed in
EP-A-0151869. For the same reasons this Frensel lens on a
human cornea does not have the optical effect of a Frensel
lens such as they are used in optics.

10

Short description of the invention

         The present invention provides a device according to
   claim 1.
15   Preferred embodiments of the device according to the
invention are characterized in the dependent claims.
         The present invention further provides a mask and
method for adapting the corneal surface of an eye as descri-
bed in claims 7 and 9.
20   Further features, advantages and details of the pre-
sent inventions will become apparent in the light of the
following description with reference to the figures:
         Figures 1 and 2 show how a profile of a cornea, as if
it were an inert surface, must be modified to correct short-
25 sightedness and long-sightedness respectively.
         Figures 3 and 4 show how a profile of a cornea, as if
it were an inert surface, must be modified to correct a
stigmatism.
         Figure 5 shows how a (static) mask A can characterize
30 a beam for controlled ablation of a determined volume of
tissue B.
         Figure 6 shows a (rotation) mask C and a similarly
circular symmetrical profile D which can be eroded by "il-
luminating" the rotating mask C with a homogeneous laser
35 beam.
         Figure 7 shows a (translation) mask E and a similarly
elongate profile F which can be eroded by "illuminating" the
sliding mask E with a homogeneous laser beam.

Figures 8 and 9 show how a hyperplasia of the epithe-
lium can partly compensate a curvature correction.

Figure 10 shows the laser system which can consist of
a laser device 1 which excites the radiation 2, a
5 homogenizer 3 which brings about a homogeneous flux density
distribution, a beam divider 4 which feeds a laser beam
monitor 5 for measuring the flux density distribution, and a
mask rotator or mask translator 6 with mask 7. The whole can
be held in an envelope 8 with dry nitrogen. This nitrogen
10 allows unobstructed passage of the UV radiation and prevents
the formation of ozone which has an adverse affect on the
laser beam.

Figures 11 and 12 show two possible arrangements of
the rotating or sliding mask.
15 Figures 13 and 14 show a profile, a projection and a
top view of the cornea with an optical zone and
stabilization zone for correction of short-sightedness.

Figure 15 shows an example of a (rotation) mask sui-
table for myopia correction.
20 Figures 16 and 17 show a profile, a projection and a
top view of optical zone and stabilization zone for correc-
tion of long-sightedness.

Figures 18 and 19 show two possible forms of masks
suitable for hyperopia correction.
25 Figures 20 and 21 show a (rotation) mask suitable for
correction of hyperopia with astigmatism and the angular
speed of this mask as a function of the rotation position
relative to the axis of the astigmatism.

Figures 22 and 23 show a profile, a projection and a
30 top view of optical zone and stabilization zone in the case
of astigmatism and correction by making flatter one meridian
with stabilization zone.

Figures 24 and 25 show the form of a (translation)
mask suitable for the correction of astigmatism by
35 flattening of one meridian with a well defined translation
relative to the cornea.

Figures 26 and 27 show a profile, a projection and a
top view of optical zone and stabilization zone in the case

of astigmatism and correction by making one meridian with
stabilization zone more curved.

Figures 28 and 29 show a form of a (translation) mask
suitable for correction of astigmatism by making more curved
5 one meridian with a well defined translation relative to the
cornea.

The entirety of mask in the mask rotator or in the
translator can be placed at different distances from the
eye, wherein one of the two following possibilities is
10 preferred.

According to the first configuration, the mask
rotator (or translator) is situated (fig. 11) on the axis of
the laser beam at for instance 20 cm from the eye of the
patient, wherein the laser beam projects the mask profile
15 onto the eye and wherein the eye is localized in the beam
bundle and mechanically fixed or is fixed by a conscious
effort of the patient who fixes his gaze (and therefore his
eye) on a particular point in space so that the optical axis
coincides with the axis of the beam bundle.
20 According to the second configuration (fig. 12) the
mask rotator or translator is fixed on the cornea or on the
eye and centered on the optical axis of this eye. Fixation
can take place with a suction ring or in other conventional
manner.
25 The mask rotator is simpler of construction if it has
to be placed in the beam bundle at some distance from the
eye, while in the second method it is built into a device
that is placed on the eye. In this latter embodiment the
mechanism is finer and lighter and ventilation of the
30 corneal surface during the procedure is slightly more
difficult. Ventilation of the corneal surface appears to be
useful for removal of debris and ablation products.

Each (remodelled) cornea surface and also the change
in topography or the volume for ablation can be described by
35 one or more quadratic equations.

Taking into account the biodynamic properties of the
epithelium in order to give an increasingly more stable
character to the curvature correction results in a sometimes

complex topographical correction which preferably satisfies
the following boundary conditions:
        - the function which describes the contour of the
optical zone must correspond with that of the desired
5 spherical or spherical-cylindrical surface.
        - the first derivative of the functions describing
the contour of the remodelled surface consisting of optical
and stabilization zone and the edge of the unmodified
surface must be a continuous variable.
10   - the whole correction must fall within the zone of
the corneal surface of the patient.
        - within the limits set by the above described boun-
dary conditions the curvature (1÷radius of curvature) must
be minimal at each distance r from the optical centre.
15   - several arbitrary boundary conditions are the mini-
mum diameter of the optical zone and the maximum cornea
volume for ablation (the maximal ablation depth).
        As example in the illustrations we selected an
optical zone of a minimum 4 mm diameter and a stabilization
20 zone of a maximum 8 mm diameter. The ideal ratios may
however differ herefrom.
        Additional limitations may further be imposed by the
laser device and the eventual mask rotator or the cornea.
        Since in preference for each distance r (or x) from
25 the rotation centre (or the translation axis), the aperture
theta (or the opening distance y) is proportional to the
depth of the tissue for removal, these functions can be
converted into a correspondingly rotatable and/or transla-
table (or sliding) mask.
30   It can be of importance to make the global surface
area of a window maximal to make the most efficient possible
use of the laser beam.
        For each type of ametropia the present invention
provides a specific laser beam characterizing system which
35 provides an optical zone and a well defined stabilization
zone and whereof six embodiments are described below.
        The masks in question are preferably manufactured
from a thin sheet of non-eroding material such as inox or

brass and the windows are cut out in a mathematically exact
manner by one of the modern micro-processing methods such as
cutting with the YAG-laser or wire spark erosion. They are
so designed that they can be rapidly placed into and removed
5 from the rotator.

In a photorefractive procedure using rotator or
translator the mask is returned after one or more full
revolutions to its original position when correcting a
hyperopia or a myopia, or, in the case of astigmatism
10 correction, it has covered a well defined trajectory one or
more times.

In the correction of myopia the profile consists of a
central optical zone with the desired radius of curvature
and an annular stabilization zone with an intermediate
15 radius of curvature (fig. 13 and 14). The corresponding
mask, an example of which is shown in fig. 15, is a first
embodiment of the present invention. The portion of the
window inside the dashed line serves to characterize the
optical zone; the portion outside the dashed line
20 corresponds with the stabilization zone. Characteristic here
is that the stabilization zone is comparatively narrow
compared to the optical zone. Many other embodiments are
possible, but they comply with the same general formula. The
hyperplasia of the epithelium centrally in the optical zone
25 is restricted to a minimum with this mask.

In the correction of hyperopia as in fig. 2, the
remodelled surface can be made to transpose into the
original surface in an annular stabilization zone. Taking
into account the biodynamic properties of the epithelium, a
30 profile as shown in fig. 16 is to be preferred. This profile
satisfies the above described boundary conditions. In a top
view of the cornea (fig. 17) three zones can be
distinguished: the central circle of the optical corrected
zone, an annular stabilization zone and a rim of the
35 original cornea surface. In the stabilization zone the
corrected surface merges gradually and in specific manner
into the original surface. The ratio of the radius of the
optical zone to that of the stabilization zone (here 1/2)

can be further optimized depending on the intended
correction.

The corresponding (rotation) mask, which is a second
realization of the present invention, has a very specific
5 form: a first design (fig. 18) has two windows and two spo-
kes. A second design (fig. 19) has three windows and three
spokes. The portion of the window inside the dashed line
serves to characterize the optical zone; the portion outside
the dashed line corresponds with the stabilization zone.
10 Characteristic here is that the maximum thickness for abla-
tion and the maximum aperture lie outside the optical zone
in the stabilization zone. Many other embodiments are
possible but they all comply with the equivalent formula.
The rotation speed and the number of revolutions are well
15 defined and a function of the maximum depth for ablation,
i.e. of the extent of the optical correction.

In a third embodiment this invention proposes a
method and device for correction of a hyperopia in
combination with a slight astigmatism. It is a variant of
20 the second aspect of this invention, i.e. it comprises a
mask the shape of which complies with the general
description for hyperopia correction and is characterized by
the fact that there are only two windows, with a symmetry
around the X-axis and the Y-axis and such that one window
25 can be written in one quadrant of the mask. The mask is
subjected to a rotation in two phases: in a first phase the
hyperopia is corrected, in a second phase the astigmatism.
The angular speed is constant in the first phase and
displays a variation per revolution in the second phase as
30 according to fig. 21: such that in this second phase the
exposure period of the cornea zone perpendicular to the axis
of the astigmatism is greater than that of the cornea zone
in the axis of the astigmatism. This generates a cylindrical
component in the remodelled cornea and permits the use of
35 the same mask for both types of correction.

For a stable correction of astigmatism by flattening
one meridian (as in fig. 3), this invention proposes to
correct the curvature in the said meridian as in fig. 22

with a narrow stabilization zone and, in the meridian
perpendicular thereto - above and below -, to have the
remodelled surface surrounded by a stabilization zone
bounded by the shape of the window and the limited
5 translation and characterized by the fact that the window
does not pass thereover (fig. 23 and 24) along its whole
maximum opening distance (in the translation axis).

The meridian in the translation axis preserves the
same radius of curvature in the region where the window
10 passes over its whole height (opening distance) because a
peel of equal thickness is ablated over this region. In the
region where the window does not pass over its whole height
the ablated peel becomes increasingly thinner and the
ablated surface in the meridian of translation merges
15 gradually into the original surface having the same radius
of curvature (fig. 22).

The corresponding (translation) mask, which is a
fourth embodiment of the present invention, has a specific
shape (fig. 25), characterized by a symmetry about the X-
20 axis and the Y-axis and bounded by two paraboloids. It is
subjected to a well defined translation movement (fig. 24)
with well defined starting and finishing points relative to
the cornea and with a translation speed which is a function
of the maximum depth for ablation. Characteristic here is
25 that in its starting and finishing positions the window
falls completely outside the optical zone.

There are possibilities other than that shown in fig.
25. Resulting from laser photoablation with characterizing
of the laser beam in this manner is a corneal topography
30 which is flattened in one meridian, with this meridian
having a (narrow) stabilization zone and the meridian of
translation having an unchanged radius of curvature in the
optical zone due to a uniform ablation with a specific
stabilization zone as in fig. 23.

35   The translation axis is parallel to the axis of a
negative cylindrical glass necessary for correction of the
eye.

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For a stable correction of astigmatism by making one
meridian more curved (fig. 4) the invention proposes to
correct the curvature in the said meridian as in fig. 26 and
to have the remodelled surface surrounded by a butterfly-
5 shaped stabilization zone bounded by the shape of the window
(fig. 29) and the limited translation. The shape of the
window ensures that the curvature correction both in the
corrected meridian and in the direction perpendicular
thereto extends slopingly outward in accordance with the
10 biodynamic properties of the cornea. Characteristic here
also is that the maximum thickness for ablation and the
maximum opening distance of the (translation) mask lie
outside the optical zone in the stabilization zone. The
meridian in the translation axis centrally in the optical
15 zone preserves the same radius of curvature because nothing
is ablated over this region.

The corresponding (translation) mask, the example of
which in fig. 29 is a fifth realization of the present
invention, has a specific shape characterized by a symmetry
20 about the X-axis and the Y-axis and is subjected to a well
defined translation movement (fig. 28) with well defined
starting and finishing points relative to the cornea and
with a translation speed which is a function of the maximum
depth for ablation. Characteristic here is that in its
25 starting and finishing positions the window falls completely
outside the optical zone.

Resulting from laser photoablation with
characterisation of the laser beam in this manner is a
corneal topography with an increased curvature in one
30 meridian, while the meridian in the axis of translation
remains unchanged.

The translation axis is parallel to the axis of a
positive cylindrical glass necessary for correction of the
eye.

35 It is self-evident that the mixed ametropias can be
corrected by a succession of various of the above described
methods and devices. The experimental results have as yet to

confirm the correct ratios of optical zone and stabilization
zone in the different types of correction.

In a preferred arrangement the flux density distribu-
tion of the laser beam is made homogeneous by a laser beam
5 homogenizer, some types of which are commercially available,
such as from the firm Exitech, Long Hanborough, Oxford, UK,
and this homogenizing process is continually controlled by a
laser beam monitor, likewise available from the same firm.
In the applications described above use is made each time of
10 an excimer laser beam, the diameter of which is preferably
sufficiently large to simultaneously illuminate the whole
mask with all windows and the optical zone and stabilization
zone on the cornea.

A first and main advantage is that with a single,
15 relatively simple device a central and a peripheral part of
the laser beam is characterized with a view to stable
correction of an ametropia by a topographical change that is
a combination of a curvature correction in the optical zone
and a curvature adaptation in the so-called stabilization
20 zone, taking into account the biodynamic properties of the
epithelium.

A second and particularly advantageous property of
these masks is that a greater or smaller dioptric correction
can be obtained by causing the illumination period or number
25 of pulses on the same mask to increase or decrease: the
maximum ablation depth hereby increases or decreases, abla-
tion depth being the product of the number of pulses multi-
plied by the ablation depth per shot or laser pulse.

A third advantage is that the shape of a window can
30 be made very precisely and mathematically exact with the
present micro-processing methods and that this shape is
fixed and much more stable than for instance a variable
transmission characteristic of a mask, of which it is known
that it can change under the influence of the laser beam.
35 The effect of the shape of the window on the ablation depth
is easier to predict than for instance the effect on the
ablation of an erodible "phantom" lens.

A fourth advantage is that the largest
discontinuities that are formed on the surface are the size
of the ablation thickness of one shot, whereby the
remodelled surface is smoother and does not display any
5 concentric stages as in some other systems.

A fifth advantage is that it is a comparatively inex-
pensive device because the masks can be re-used.

CLAIMS

1. Device for adapting an anterior corneal surface of
an eye, comprising:
    - a laser for generating a laser beam;
    - a homogenizer for homogenizing the laser beam
5 coming from the laser with substantially circular
symmetrical flux density change;
    - at least one mask arranged between the eye and the
homogenizer; and
    - a member for causing the mask to translate and/or
10 rotate, wherein the translation and/or rotation movement and
the shape of the mask are adapted to one another such that
in radial direction of the anterior corneal surface a
transition zone is provided in which the adapted central
portion of the anterior corneal surface gradually merges
15 into the original, non-modified corneal surface.
    2. Device as claimed in claim 1, wherein the mask
comprises a number of windows in a plate of a non-erodible
material that has absolutely no transmission for the laser
beam used.
20   3. Device as claimed in claim 1 or 2, wherein the
mask is placed at a short distance, for instance a few
millimetres from the eye, above the cornea.
    4. Device as claimed in claim 1 or 2, wherein the
mask is placed at a distance of approximately 20 cm above
25 the eye.
    5. Device as claimed in any of the claims 1-4,
wherein the mask is rotated and wherein the mask has a
rotation-symmetrical form with preferably two lobe-shaped
windows.
30   6. Device as claimed in any of the claims 1-5,
wherein the mask has butterfly-shaped windows.
    7. Mask for use in the device as claimed in any of
the foregoing claims, wherein the geometrical form of the
windows roughly corresponds with that of the figures.

18

8. Mask for use in the device as claimed in any of
the foregoing claims, provided with a first central window
portion for the central portion of the cornea and a
peripheral window portion for the transition zone.

5   9. Method for adapting the anterior corneal surface
of an eye, wherein a new curvature is given to a central
portion of the cornea and wherein for stabilizing this new
curvature a stabilization ring is arranged around the
central portion in the anterior cornea using the same laser
10 beam with which the new curvature is arranged so that there
results a stable transition to the portion of the cornea not
treated with a laser bundle.
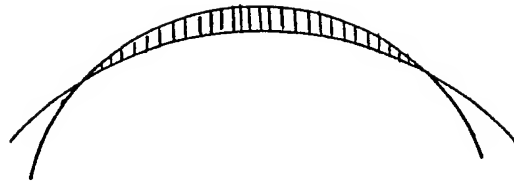
FIG.1

FIG.2

FIG.3

FIG.4

A

B

FIG.5

C

D

FIG.6

2/5

E

F

FIG.7

FIG.13

y

x
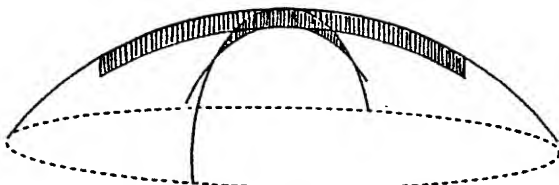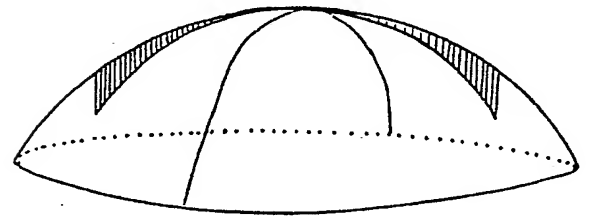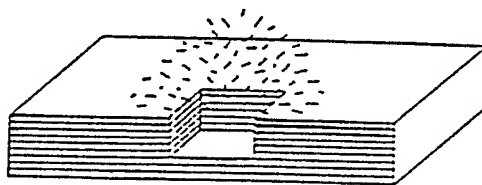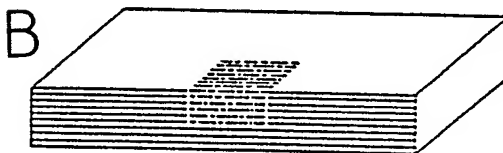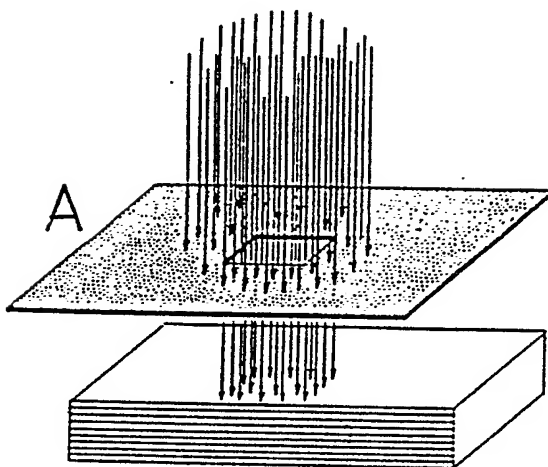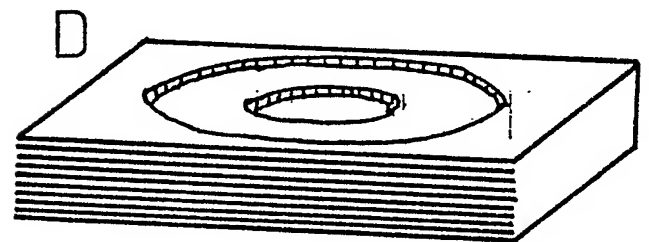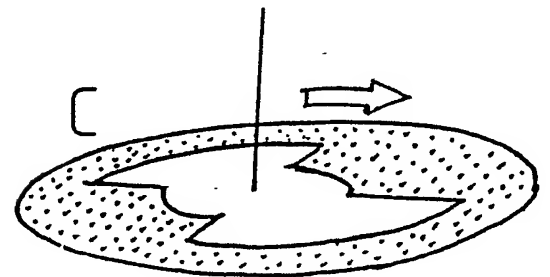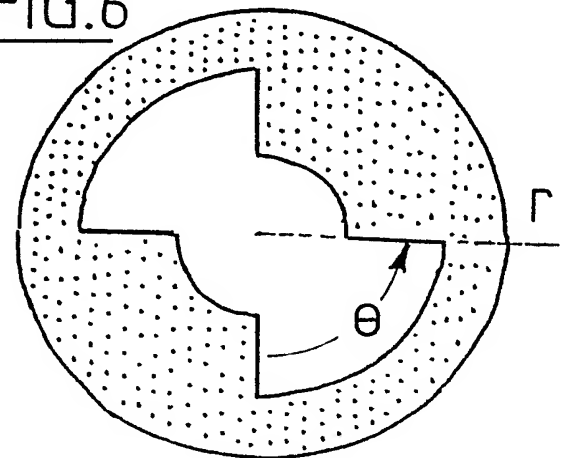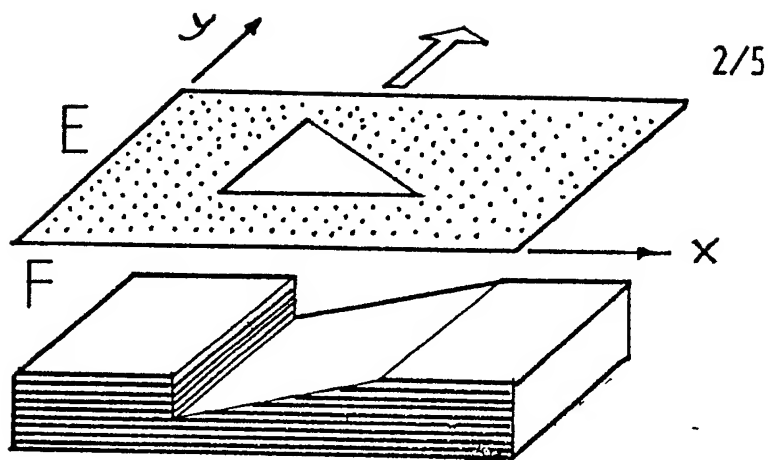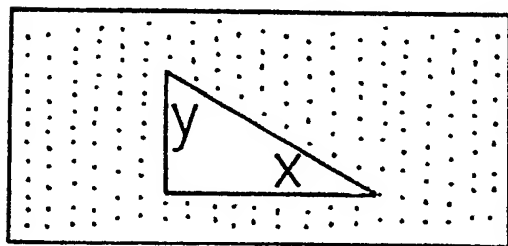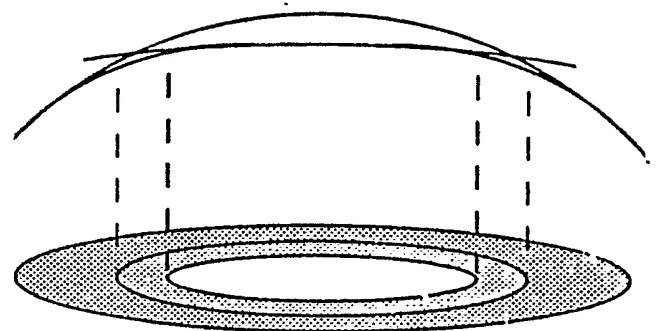
OPTICAL

STABILIZATION

FIG.15

FIG.14

3/5

FIG.8

FIG.9

FIG.10

FIG.11

FIG.12
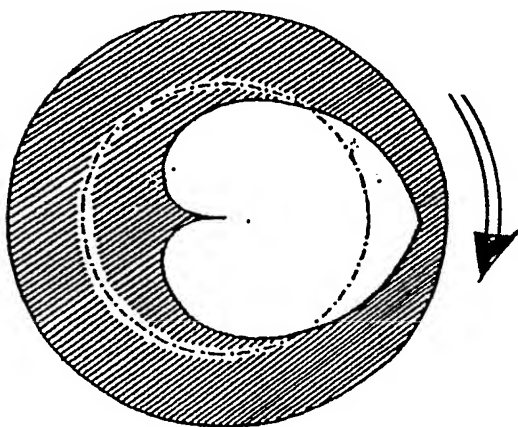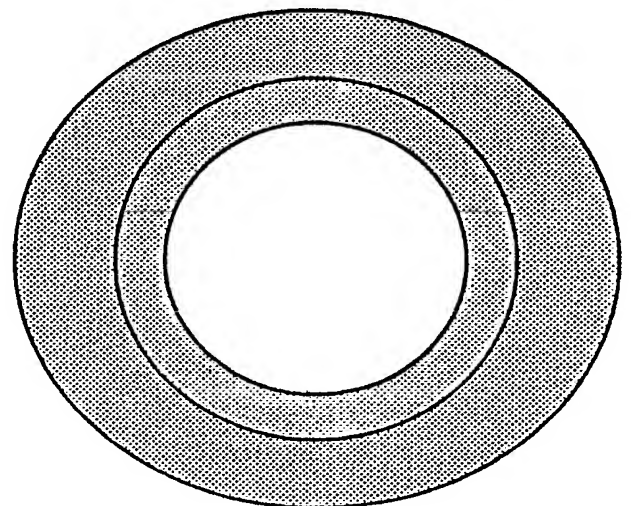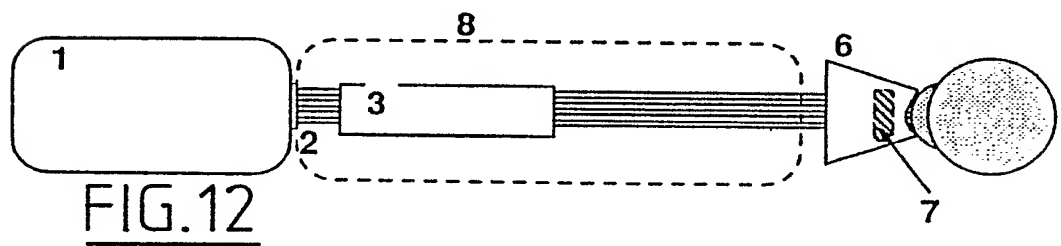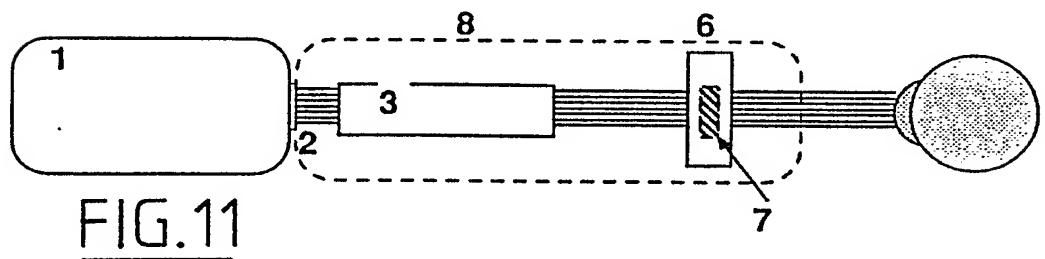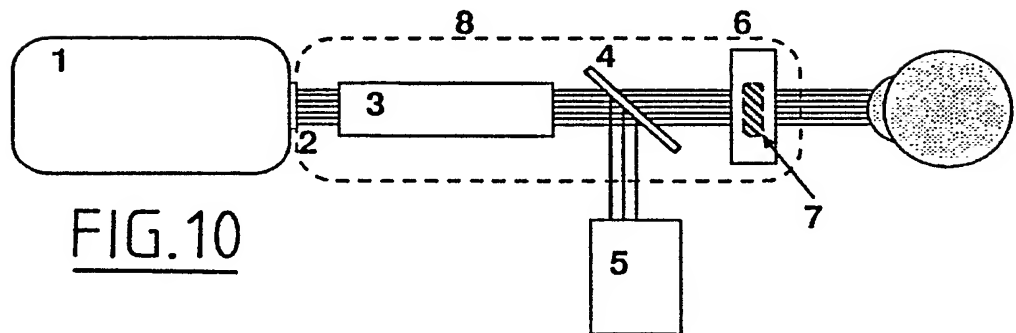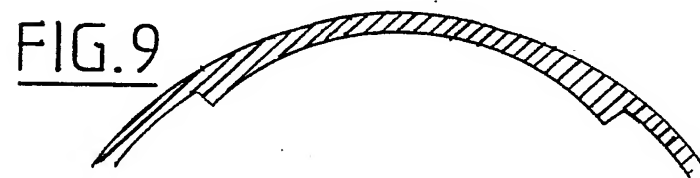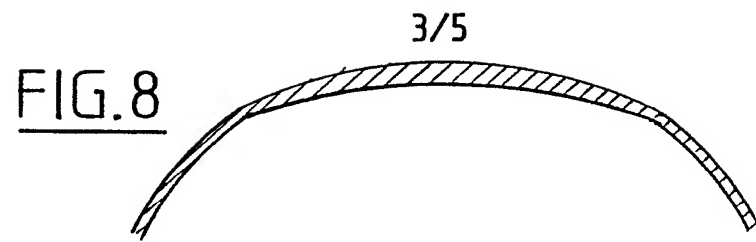
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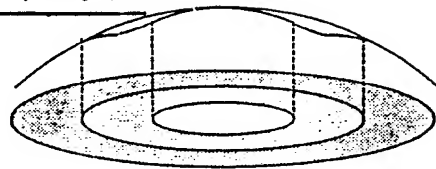
OPTICAL

STABILIZATION

FIG.17

FIG.18

FIG.19

FIG.20

FIG.21

ANGULARRATE

NUMBER OF

n   n+1   ROTATIONS
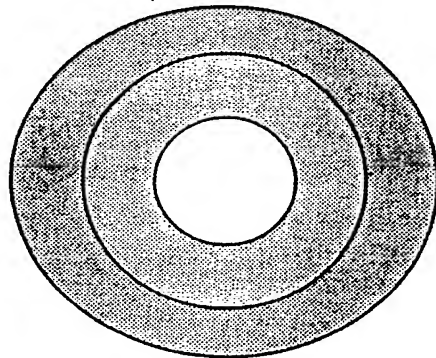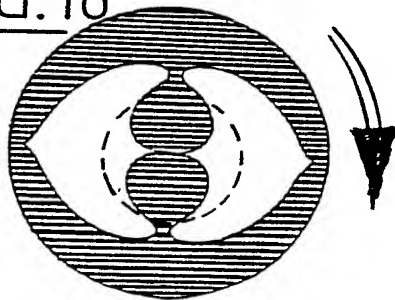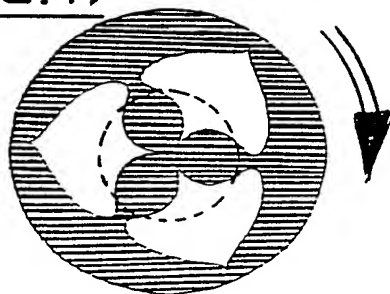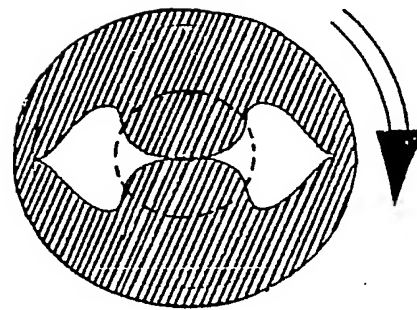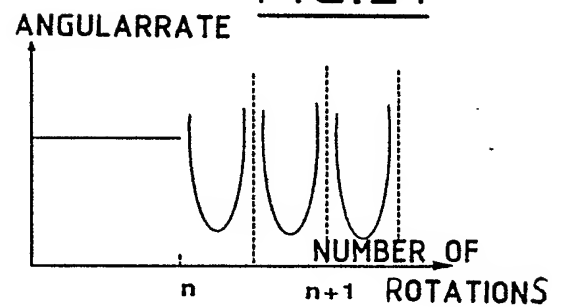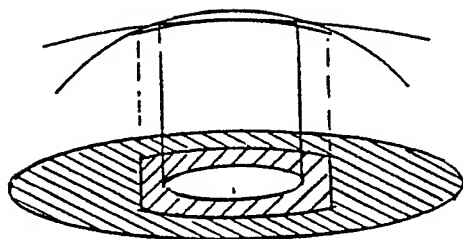
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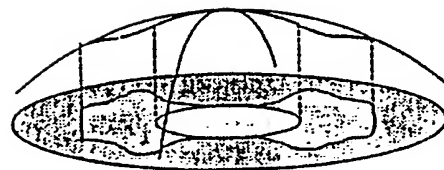
STABILIZATION

FIG.26   OPTICAL

STABILIZATION

FIG.23
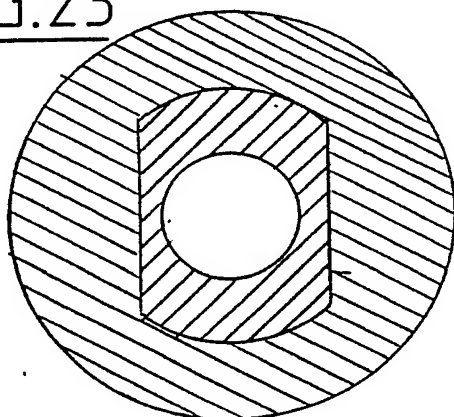
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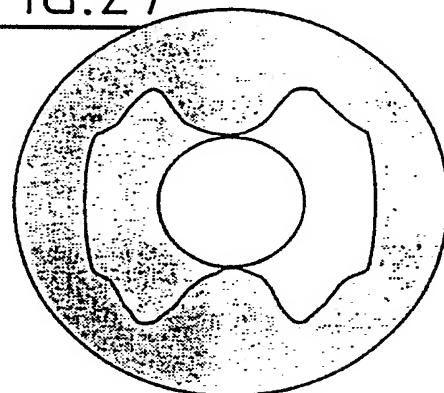
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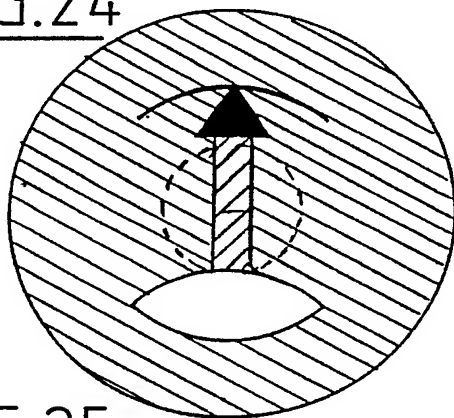
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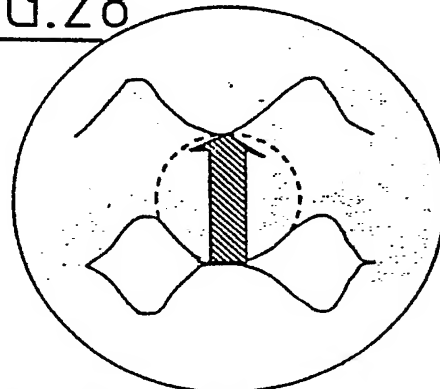
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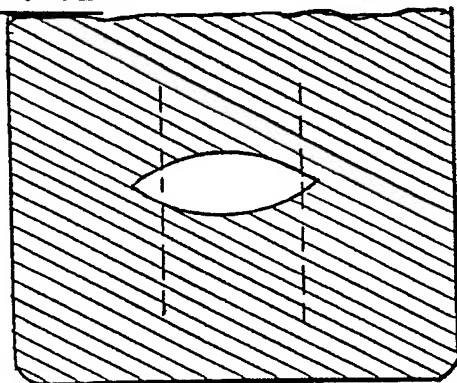
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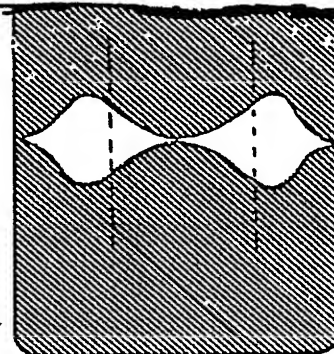
INTERNATIONAL SEARCH REPORT

International Application No PCT/BE 91/00007

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 6

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC[5]: A 61 F 9/00

II. FIELDS SEARCHED

Minimum Documentation Searched 7	
Classification System	Classification Symbols
IPC[5]	A 61 F

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 8

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

Category *	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No. 13
X	DE, A, 3615042 (DARDENNE) 12 November 1987 see figure 1; column 11, lines 15-21; column 12, lines 44-49	1-3,5,6,8
Y	--	4
Y	EP, A, 0296982 (HANNA) 28 December 1988 see figure 7; page 10, lines 61-65; figure 4; page 13, lines 48-51	4
A	--	1,5
A	US, A, 4770172 (L'ESPERANCE) 13 September 1988 see column 3, lines 17-43	1
A	FR, A, 2633826 (MIKROKHIRURGIA GLAZA) 12 January 1990 --------	

* Special categories of cited documents: 10

"A" document defining the general state of the art which is not considered to be of particular relevance

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
3rd May 1991	2 7. 06. 91
International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	Danielle van der Haas

Form PCT/ISA/210 (second sheet) (January 1985)

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

incompletely

V.[X] OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1.[X] Claim numbers 9 because they relate to subject matter not required to be searched by this Authority, namely:

Pls. see Rule 39.1 (iv) - PCT:

Methods for treatment of the human or animal body by surgery or therapy, as well as diagnostic methods.

2.[X] Claim numbers 7 , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out. specifically:

Claim 7 searched incompletely
"Claims shall not, except where absolutely necessary, rely, in respect of the technical features of the invention, on references to the description or drawings. In particular, they shall not rely on such references as: "as described in part... of the description," or "as illustrated in figure... of the drawings (Rule 6.2 (a) - PCT)

3.[ ] Claim numbers........., because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI.[ ] OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

1.[ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2.[ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3.[ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4.[ ] As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

[ ] The additional search fees were accompanied by applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (supplemental sheet (2)) (January 1985)

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 18/06/91
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
DE-A- 3615042	12-11-87	None		
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		JP-A-	1086968	31-03-89
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